

Small-Volume Fluid Resuscitation for the Far-Forward Combat Environment: Current Concepts

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Hemorrhage remains the primary cause of death on the battlefield in conventional warfare. With modern combat operations leading to the likelihood of significant time delays in air evacuation of casualties and long transport times, the immediate goals of the Army's Science and Technology Objectives in Resuscitation are to develop limited- or small-volume fluid resuscitation strategies, including permissive hypotension, for the treatment of severe hemorrhage to improve battlefield survival and prevent early and late deleterious sequelae. As an

example, the U.S. Army has invested much effort in the evaluation of hypertonic saline dextran (HSD) as a plasma volume expander, at one tenth to one twelfth the volume of conventional crystalloids, in numerous animal models of hemorrhage. These studies have identified HSD as a potentially useful field resuscitation fluid. In addition, preliminary studies have used HSD under hypotensive resuscitation conditions, and it has been administered through intraosseous infusion devices for vascular access. This re-

search suggests that many of the difficulties and concerns associated with fluid resuscitation for treating significant hemorrhage in the field can be overcome. For the military, such observations have important implications toward the development of optimal fluid resuscitation strategies under austere battlefield conditions for stabilization of the combat casualty.

Key Words: Fluid resuscitation, Permissive hypotension, Hypotensive resuscitation, Small volume, Intraosseous.

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Hemorrhage accounts for 50% of battlefield deaths in conventional warfare and 30% of casualties who die from wounds.¹ From these statistics, it has been suggested that 65% to 80% of casualties may require some amount of fluid. Lessons learned by the British in the Falkland Islands War confirmed that early fluid resuscitation improved survival (R. Mosebar, personal communication). In a recent consensus conference, Butler et al.² concluded that fluid resuscitation was necessary for any casualty with a change in mental status or a casualty who is unconscious, suggesting a systolic blood pressure less than 50 mm Hg.

OBSTACLES TO MEDICAL CARE ON THE BATTLEFIELD

It is well recognized that limitations exist in providing far-forward resuscitation on the battlefield. For example, large volumes of resuscitation fluids cannot be carried into the field, and there can be significant time delays and failure

rates in obtaining peripheral intravenous access in the field. In addition, the medic has only limited training, and delayed transport to definitive medical treatment facilities is a high probability. Nevertheless, evidence from experimental animals suggests that interventions to reestablish homeostasis may need to be initiated within 30 minutes after injury to ensure survival.³

Future combat scenarios imply that delays of 24 hours before evacuation of casualties may be common, and delays as long as 96 hours may occur in obtaining air evacuation of battlefields. Lessons learned from Somalia indicate that evacuation from urban battlefields may be quite delayed.⁴ The implication is that several hours may pass before any surgical intervention to treat the injured soldier is possible. In addition, special operations forces operate under the assumption that evacuation of casualties could be delayed for up to 72 hours. As indicated by Bellamy,¹ mortality increased from 20% to 32% when evacuation of casualties was delayed from immediately to 24 hours. Although his data did not extend beyond 24 hours, the mortality rate would be expected to continue to increase beyond this point, but whether this increase would be linear or exponential is unknown.

PERMISSIVE HYPOTENSION

On the basis of this information, the goals of fluid resuscitation by the U.S. Army are to develop a strategy to improve field resuscitation for combat casualties expecting delayed evacuation and limited availability of resources. Discussions at a workshop held at the 1998 Special Operations Medical Association meeting have led to the concept of permissive hypotension as a far-forward treatment strategy for special operations forces.² Permissive hypotension was

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recognized as a reasonable approach in the care of combat casualties in World War I and World War II.^{5,6}

Today, traditional fluid resuscitation practice to normalize the blood pressure rapidly is being challenged, especially for treating hemorrhagic shock victims with penetrating injuries.^{7,8} It has been argued that normotensive resuscitation can increase bleeding and worsen outcome because of severe hemodilution and disruption of newly forming blood clots. Thus, permissive hypotensive resuscitation has been introduced to avoid these consequences.^{7–10} Studies in experimental animals have shown that in the treatment of uncontrolled hemorrhage from a vascular injury, restoring blood pressure to 40 or 60 mm Hg resulted in longer survival compared with animals resuscitated to the baseline mean arterial pressure of 80 mm Hg or animals that received no fluid.^{11,12} In addition, providing some fluid even before surgical repair of the injury is performed also appeared to be better than delaying all fluid until after surgery.¹¹ However, the majority of these studies have only followed animals for a few hours and lactated Ringer's (LR) or normal saline have been the primary fluids examined.^{13,14} Also, only one study in rats and one in pigs have extended the observations to 72 hours.^{11,12} Because not all animals in the hypotensive resuscitation groups survived in these studies, further investigation warrants use of different fluids, resuscitation to a higher blood pressure, or resuscitation to better physiologic endpoints in an attempt to improve outcome.

SMALL-VOLUME RESUSCITATION

To compensate for the logistic problems of providing enough crystalloid fluids on the battlefield to resuscitate the injured soldier adequately, the U.S. Army initiated studies to investigate the potential efficacy of resuscitation fluids that could be effective in small volumes. As a result, much time and effort were invested in evaluating 7.5% NaCl/6% dextran-70 (hypertonic saline dextran [HSD]). Results from pre-clinical and clinical studies have shown the efficacy of HSD for the treatment of significant hemorrhage.^{15–20}

It is also recognized that the presence of hypotension, environmental and tactical conditions, limited expertise of the medic, and/or the presence of mass casualties can lead to significant time delays and failures in gaining vascular access in the far-forward combat arena. On the basis of evidence to suggest that intraosseous (IO) infusion is a viable route for the emergency injection of drugs and fluids²¹ and that the technique was easy to learn by military first responders,²² the U.S. Army, through in-house research activities and outside contracts, has examined the intraosseous route as an alternative means of infusing resuscitation fluids for the treatment of hemorrhagic hypotension in experimental animals.^{23–25} These studies observed that a single dose of HSD was as effective through the IO route as the intravenous route.^{23–25} In addition, where studies with IO infusion of isotonic crystalloids indicated that such administration could not resuscitate from hemorrhagic hypotension in a timely manner,²⁶ IO administration of HSD could be effective.²⁴

The safety of IO infusion of a single dose of HSD has been reviewed in recent years, and no major tissue damage was observed, either a few hours after infusion or at 2 weeks.²⁵ However, most recently, Alam et al.²⁷ reported that multiple IO infusions of hypertonic saline caused severe necrosis of the tibia 2 days after its infusion into the tibia of dehydrated pigs. Although these studies need confirmation, on the basis of toxicity studies of HSD and its individual components, large volumes of hypertonic fluids of any composition could be expected to induce tissue necrosis if the dose extravasated into soft tissue.²⁸ Taken together, these studies may suggest limiting IO use of hypertonic fluids to a single dose, but they should not detract from the large body of literature citing the successful application of IO infusion for resuscitation in emergency situations.²¹

PERMISSIVE HYPOTENSION AND HSD

Recently, a pilot study was initiated to determine whether HSD, infused through the IO route, could be used in the context of permissive hypotension to resuscitate animals subjected to an uncontrolled hemorrhage.²⁹ Ketamine-anesthetized Yorkshire-mix pigs were splenectomized and instrumented with arterial and venous catheters as previously described.¹⁰ In addition, an aortotomy wire was inserted into the infrarenal aorta. After a 30-minute baseline period, animals were bled 25 mL/kg (approximately 37% of estimated blood volume) from the femoral artery over a 30-minute period. An uncontrolled hemorrhage was induced by pulling the aortotomy wire and the animal was left undisturbed for 15 minutes. Fluid resuscitation with HSD or LR was initiated through an IO sternal access device until a systolic blood pressure of 70 mm Hg was achieved. This pressure was maintained at this level with the appropriate fluid over a 2-hour experimental period. The results of these studies indicated that the volume of HSD required to maintain systolic blood pressure at 70 mm Hg was less than 10% of the volume of LR needed, similar to the data obtained with bolus infusions of HSD.^{16,17,29}

In summary, HSD and the IO administration route are consistent with the concept of permissive hypotension, and suggest that innovative means can be explored for resuscitating injured soldiers from severe hemorrhage in the far-forward combat environment. However, much remains to be investigated with respect to the concept of permissive hypotension. For example, it is not known whether permissive hypotension would worsen the incidence of late complications that could arise from incomplete resuscitation. In addition, evidence would suggest that resuscitation to a systolic blood pressure of 80 mm Hg would be inadequate to improve cerebral perfusion after head injury. Also, to date, most fluid resuscitation studies evaluating permissive hypotension have generally used crystalloids such as LR or normal (physiologic) saline. Recently, Burris et al.³⁰ suggested that at least short-term outcome can be improved by resuscitating to a lower blood pressure with a hypertonic saline-hemastarch fluid

than with LR. Additional research is warranted to determine the optimal fluid that can be used in small volumes, and to improve outcomes even in situations where definitive care is delayed for many hours after injury.

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